2013

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Recommended Citation

Fufa, Duretti; Calfee, Ryan; Wall, Lindley; Zeng, Wenjing; and Goldfarb, Charles, ,"Digit Replantation: Experience of two U.S. academic level-I trauma centers." The Journal of Bone and Joint Surgery.95,23. 2127-2134. (2013).
http://digitalcommons.wustl.edu/open_access_pubs/2008

Digit Replantation: Experience of Two U.S. Academic Level-I Trauma Centers

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Investigation performed at Barnes-Jewish Hospital, Washington University in St. Louis, St. Louis, Missouri, and University of Cincinnati, Cincinnati, Ohio

Background: Despite advances in microsurgery, digit replantation now is performed less frequently in the U.S. compared with fifteen years ago. There has been uncertainty regarding whether previously reported U.S. replantation success rates and results reported from other countries reflect the current experience in the U.S. We hypothesized that the success of digit replantation at two academic level-I referral hospitals in the U.S. would be similar to previously published results.

Methods: In this retrospective case series, we examined all cases of digit replantation that were performed from 1997 through 2010 at two institutions. The cumulative rate of viable digit replantations was determined. Binary logistic regression modeling determined the relative impact of patient, injury, and operative factors on replantation survival.

Results: During the study period, 135 digit replantations were performed in 106 patients. Fourteen cases did not meet our inclusion criteria, yielding a cohort of 121 replantations. The thumb (n = 40) was the most commonly replanted digit, followed by the long finger (n = 31). The mechanism of injury was classified as sharp in eighty-three digits, crush in nineteen digits, and avulsion in eighteen digits. The majority of replantations were performed following Tamai level-III (n = 49) or level-IV (n = 56) amputations. Sixty-nine (57%) of the digit replantation procedures were successful. Logistic regression analysis identified replantation of the radial three digits and no history of tobacco use as significant independent predictors of replantation success.

Conclusions: The rate of success of digit replantation (57%) at two academic level-I trauma hospitals was lower than previously published rates. Radial-digit involvement and no prior tobacco use were associated with replantation success. This modest success rate reflects a need for additional evaluation of our current benchmarks and clinical settings for replantation surgery. These data help to better inform patients, families, and physicians who are considering digit replantation.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

The field of replantation surgery has progressed markedly since the first successful arm replantation by Malt in 1962, the report of successful microsurgical anastomoses in animals by Buncke in 1964, and the first successful thumb replantation by Tamai and Komatsu in 1965[1-4]. Classically, digit survival rates following digit replantation have been reported to be between 80% to 90%, depending on the indication[5-8]. Waikakul et al. reported on a series of 1018 total and subtotal replantations in which the digit survival rate was 92%[8]. A review of the literature revealed that our currently accepted replantation survival rates have been generated from literature published before the 1990s and, more recently, from Asian centers.

Whereas many early advances in microsurgical techniques were achieved in North America, in the last decade Asia has become the leader in microsurgery. Advances in Asia include a growing number of successful replantations following very distal fingertip amputations, of fingers with prolonged ischemic time, and of multiple amputated digits. Additionally, the emerging field of supermicrosurgery, which involves

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. One or more of the authors, or his or her institution, has had a financial relationship, in the thirty-six months prior to submission of this work, with an entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. No author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

microanastomoses ranging from 0.3 to 0.8 mm in diameter, was pioneered in Japan and has allowed extension of the classic indications for replantation surgery[5,9-11]. Two recent reviews highlight the importance of the contributions from Asia to our understanding of digit replantation. In one, a systematic review regarding outcomes of distal digit replantation, Sebastin and Chung evaluated thirty studies (2273 distal replantations), of which only two were from the U.S.[6]. In the other, Dec evaluated the success rates of digit replantation in a meta-analysis of eight studies, and, again, just two studies were from U.S. institutions[12]. We identified only a very few reports of digit replantation success from the U.S. in the last twenty years[5,13-15], with just two of these involving a cohort of greater than fifty patients[13,14].

A growing body of literature suggests that replantation is being performed less frequently in the U.S. today compared with fifteen years ago. Payatakes et al. reported that, in a survey regarding microsurgery in the U.S., only 56% of responding American Society for Surgery of the Hand (ASSH) members indicated that they performed replantations. Of those, the majority performed fewer than five replantations per year[16]. The literature on the epidemiology and availability of replantation surgery in the U.S. has confirmed that replantations are increasingly being performed in smaller numbers and by fewer surgeons[16-18]. Several explanations for these trends have been offered, including a declining number of amputations, declining reimbursement, complexity of the cases, and increased selectivity for attempting replantation[3,16-19]. Currently, a thorough understanding of these trends and their effect on outcomes of replantation surgery in the U.S. is lacking.

Given these observations, the aim of the present study was to investigate the volume and modern success of digit replantation in a large series from two academic level-I trauma centers in the U.S. We hypothesized that digit survival rates following digit replantation would be similar to those found in the literature.

Materials and Methods

Study Design

We performed a retrospective case series investigation after institutional review board approval was obtained at each participating center. Patients were identified for study inclusion on the basis of Current Procedural Terminology codes for digit replantation (20816, 20822, 20824, and 20827) in the period from June 1997 through December 2010 at two institutions. We reviewed the medical records, including emergency department summaries, operative reports, and radiographs, of all patients who underwent replantation of at least one digit. Patients were excluded from our series if the primary emergency surgery resulted in amputation, regardless of whether replantation was attempted or considered. We excluded all cases of incomplete amputation, as defined by Biemer[20], and any amputation proximal to the level of the metacarpal head.

Both institutions are large teaching hospitals (more than 700 beds) that are American College of Surgeons-certified level-I trauma centers offering continuous microsurgical coverage for replantation. Barnes-Jewish Hospital has a general catchment area of 300 miles (483 km) and routinely treats patients from seven surrounding states. The University of Cincinnati has a general catchment area of 150 miles (241 km) and routinely treats patients from three surrounding states. All twenty-seven surgeons who performed

TABLE I Tamai Classification of Digit Amputation Level

Level	Description*
I	Distal to FDP insertion
II	Distal interphalangeal joint to FDP insertion
III	Middle phalanx distal to FDS insertion
IV	Proximal phalanx to middle phalanx FDS insertion
V	Metacarpophalangeal joint and proximal

*FDP = flexor digitorum profundus; FDS = flexor digitorum superficialis.

replantations were either plastic surgeons or fellowship-trained orthopaedic hand surgeons.

Demographic patient data were recorded, including age, hand dominance, mechanism of injury, occupation, Workers' Compensation status, tobacco use, and evidence of comorbidities known to affect small blood vessels (diabetes, intravenous drug use, collagen vascular disorders, and coronary artery disease). Radiographs, together with emergency room and consultation notes, were used to determine the digit(s) involved and the level(s) of injury (according to the Tamai classification as described by Yoshimura[21], Table I). We reviewed operative reports to record operative details that had the potential to impact replant viability, including the number of arteries and veins repaired and the use of vein grafts. Finally, we examined surgeon experience as determined by the number of years in practice at the time of the replantation surgery. Our primary outcome was survival of the replanted digit. Survival was defined as digit viability for a minimum of twenty-one days. This definition reflects the success of the revascularization procedure, and, for the purpose of analysis, revision amputations performed after this time point were considered complications, not failures. Fourteen cases were excluded from analysis because of a follow-up period of less than twenty-one days. Cases of replantation that failed within twenty-one days were included for the purposes of analysis.

Digit re-exploration was performed at the discretion of each surgeon, and vessel revision was not considered a failure. Cases requiring a return to the operating room for amputation or revision amputation within twenty-one days following the index surgery were considered failures of replantation.

Indications and Operative Technique

The decision to attempt replantation was based on the discretion of the attending surgeon and included the following factors: amputation of the thumb, multiple-digit amputations, time from injury to arrival, appropriate transportation and condition of the amputated part (absence of a high degree of tissue damage, such as the ribbon sign[22]), and medical stability to undergo replantation. The patient's age, digit(s) amputated, and hand dominance were also taken into account in the decision-making. Single-digit replantation (excluding the thumb) was attempted when the amputation was distal to the insertion of the flexor digitorum superficialis tendon, other digits were severely injured, and the patient agreed with the physician that replantation would offer improved function.

The surgical technique included early arrival of the amputated part to the operating room for inspection and preparation of the digit under the operating microscope. A two-team approach was used, when possible, to allow for simultaneous preparation of the amputated part and the injured hand. At least one hand fellow assisted the attending surgeon in all cases, and in fifteen cases, two primary attending surgeons participated in the replantation. All replantations were performed on the basis of the protocol of the attending surgeon but were similar overall. The repairs began with osseous stabilization (longitudinal or crossing Kirschner wires, or a plate and screws). Tendon repairs were performed with nonabsorbable braided suture. With use of standard

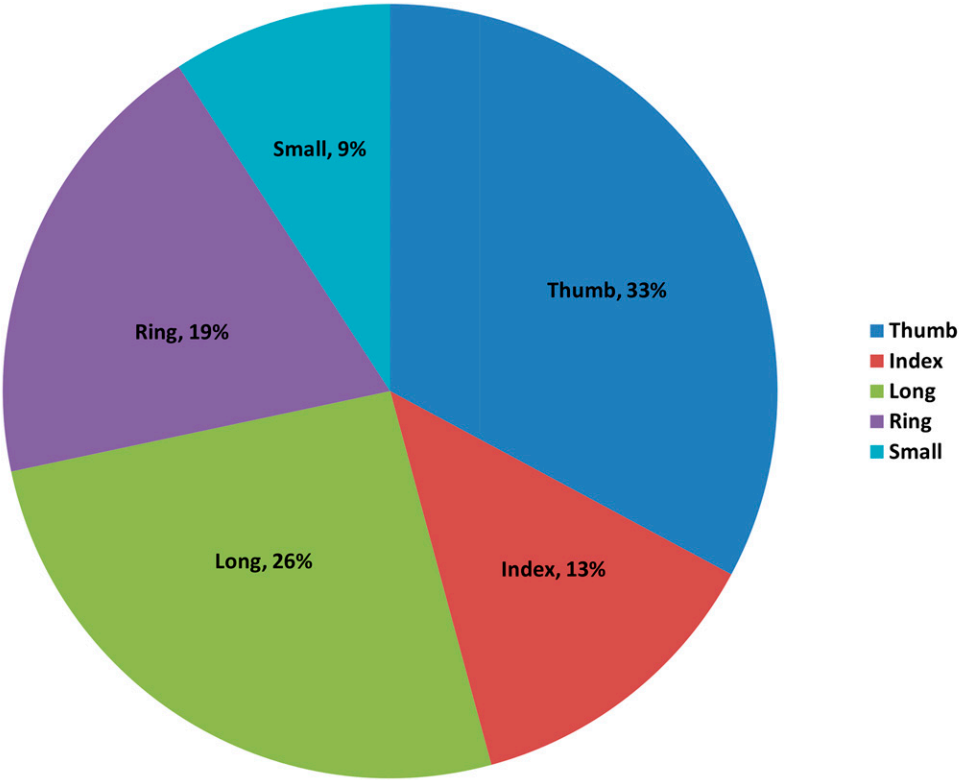

Fig. 1
Percentages of replantations by digit.

techniques (adventitial stripping and 9-0 or 10-0 nylon sutures), microsurgical repairs were performed with the use of an operating microscope, including the use of vasodilatory agents, such as lidocaine and/or papaverine, and intraoperative antithrombotic supplementation with heparin. In cases in which it was not possible to perform a tension-free repair of the vessels or nerves, vein and nerve grafts, respectively, were used.

Postoperative monitoring included hourly neurovascular checks for a minimum of twenty-four hours. Patients routinely received anticoagulation therapy postoperatively with use of heparin, dextran, and/or aspirin, on the basis of surgeon preference. Methods to treat venous congestion (heparin soaks and leech therapy) were employed as needed. Patient readiness for discharge was determined on a case-by-case basis, with discharge deemed appropriate when hospital-based interventions no longer appeared to contribute to digit survival.

Statistical Analysis

We used descriptive statistics to determine the success of digit replantation and identify the demographics of replantation in our cohort. Univariate chi-square analysis and a Fisher exact test were used to determine potential differences in replant survival rates according to categorical patient demographics, injury details, and operative techniques, with significance set at $p < 0.05$. Independent predictors of replantation survival included in this analysis were age, sex, hand dominance, digit amputated, level of amputation, mechanism of injury, smoking status, evidence of small-vessel comorbidity, number of veins and arteries repaired, use of vein graft, time from injury to surgery, and surgeon years in practice. Variables that could influence the survival of the replanted digit ($p < 0.15$ in the univariate analysis) were entered into a binary logistic regression analysis to predict the effect on replantation survival. Independent variables included in the final statistical model were assessed on the basis of their regression coefficient, and are presented with odds ratios with 95% confidence intervals (CIs) to demonstrate their effect on replant survival. The independence of independent variables was confirmed prior to their inclusion in the logistic model ($r < 0.3$ for all). Model performance was assessed on the basis of a nonsignificant result on the Hosmer-Lemeshow test, significant improvement with each block in addition to overall model significance, and assessment of the model's predictive ability regarding replantation success.

Source of Funding

No sources of funding were used in the preparation of this study.

Results

Epidemiology of Replantation (Table II)

One hundred and thirty-five digits were replanted at our institutions in 106 patients (five replantations per hospital per year on average). Fourteen cases were excluded from the final analysis because of a duration of replantation survival of less than twenty-one days, yielding a final cohort of 121 digit replantations in ninety-three patients. The average duration of follow-up was thirteen months (range, eight days to ten years). The average patient age in our cohort was thirty-nine years (range, seventeen to seventy-nine years). Four patients (seven digit replantations) in our cohort were women. The nondominant hand was more commonly injured (sixty-one of 100 cases in which hand dominance was clearly recorded). Thirty-five percent (forty-two) of the replantations were peformed in patients with a history of smoking or other tobacco use. The thumb was the most commonly replanted digit (33% of the cases) (Fig. 1), and a sharp mechanism of injury was the most common mechanism (Fig. 2). Eighty-seven percent of the

TABLE II Univariate Associations Between Digit Survival and Variables

Variable	No. (%) of Digits that Survived	No. (%) of Failures	Total	P Value
Age				0.62
<30 yr	19 (53)	17 (47)	36	
30-59 yr	43 (57)	32 (43)	75	
≥60 yr	7 (70)	3 (30)	10	
Total			121	
Sex				0.237
Male	63 (55)	51 (45)	114	
Female	6 (86)	1 (14)	7	
Total			121	
Dominant hand*				0.241
Yes	21 (54)	18 (46)	39	
No	40 (66)	21 (34)	61	
Total			100	
Digit				0.055
Thumb	27 (68)	13 (33)	40	
Index	10 (63)	6 (38)	16	
Long	20 (65)	11 (35)	31	
Ring	8 (35)	15 (65)	23	
Small	4 (36)	7 (64)	11	
Total			121	
Tamai level				0.43
II	4 (67)	2 (33)	6	
III	26 (53)	23 (47)	49	
IV	31 (55)	25 (45)	56	
V	8 (80)	2 (20)	10	
Total			121	
Time from injury to surgery*				0.891
<6 hr	22 (51)	21 (49)	43	
6-10 hr	10 (56)	8 (44)	18	
>10 hr	3 (50)	3 (50)	6	
Total			67	
Mechanism of injury*				0.576
Sharp	46 (55)	37 (45)	83	
Crush	13 (68)	6 (32)	19	
Avulsion	10 (56)	8 (44)	18	
Total			120	
Tobacco use*				0.037†
Yes	19 (45)	23 (55)	42	
No	47 (65)	25 (35)	72	
Total			114	
Artery repair*				0.684
1 artery	49 (58)	35 (42)	84	
2 arteries	19 (54)	16 (46)	35	
Total			119	
Vein repair*				0.048†
0 or 1 vein	21 (46)	25 (54)	46	
Multiple veins	48 (64)	27 (36)	75	
Total			121	

TABLE II (*continued*)

Variable	No. (%) of Digits that Survived	No. (%) of Failures	Total	P Value
Vein graft*				0.776
Yes	17 (55)	14 (45)	31	
No	52 (58)	38 (42)	90	
Total			121	
Small-vessel comorbidity				0.092
Yes	7 (39)	11 (61)	18	
No	62 (60)	41 (40)	103	
Total			121	
Surgeon years in practice				0.564
<5	25 (49)	26 (51)	51	
5-9	17 (57)	13 (43)	30	
10-19	17 (68)	8 (32)	25	
≥20	10 (67)	5 (33)	15	
Total			121	

*Hand dominance, mechanism of injury, tobacco use, time from injury to surgery, artery repair, vein repair, and vein graft are based on the subset of cases for which these data were available. †A significant variable.

replantations were performed following amputations at Tamai level III (forty-nine replantations) or level IV (fifty-six replantations) (Fig. 3). Of the ninety-three patients, seventy-three underwent single-digit replantation and twenty underwent multiple-digit replantation. Forty of the single-digit replantations involved the thumb. Indications to perform single-digit replantation in the remaining cases included amputation distal to the flexor digitorum superficialis tendon (n = 3), mutilating injury to other digits (n = 24), and surgeon discretion or no absolute indication identified in the chart (n = 6). The time from injury to the start of the surgical procedure, which was noted in the medical record for sixty-seven cases (Table II), averaged six hours (range, two to twelve hours). The average number of days spent in the intensive care unit and the average number of days until hospital discharge were five and eight days, respectively.

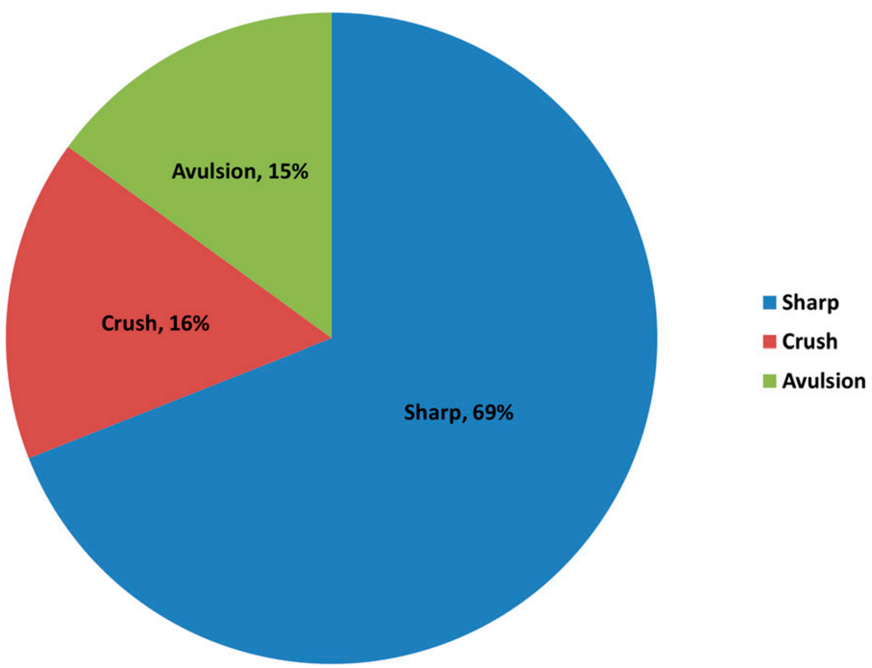

Fig. 2
Percentages of replantations by mechanism.

TABLE III Final Logistic Model of Factors Associated with Replantation Survival

Variable	B	Odds Ratio (Adjusted)	95% CI	Wald χ2 Test	P Value
Thumb, index, or long digit	1.60	4.95	1.945-12.589	11.26	0.001*
Small-vessel comorbidity	1.11	3.04	0.987-9.388	3.755	0.053
No tobacco use history	1.10	3.01	1.265-7.172	6.205	0.013*

*A significant variable ($p < 0.05$).

Success of Digit Replantation

Sixty-nine (57%) of the 121 replanted digits survived. The average time to failure was eight days (range, one to nineteen days). Eight (15%) of the failures occurred in the immediate postoperative period, between one and three days following replantation. Twenty-six (50%) of the failures occurred within the first week following replantation. In just two cases, a secondary procedure aimed at revascularization was attempted; one had arterial revision anastomosis and the other, venous revision anastomosis. Both of these cases ultimately had digit amputation, one on day six and one on day nine following second-look surgery.

We began by testing thirteen independent variables for univariate association with replantation survival. Age, sex, dominant hand, mechanism of injury, time from injury to start of surgery, number of arteries repaired, use of vein grafts, and surgeon years in practice were not associated with digit survival (Table II). Independent variables that were found to be potentially correlated with each other—mechanism of injury and level of amputation, smoking and small-vessel comorbidity—were examined and were verified not to be highly correlated ($r_s = 0.16$ and $r_s = 0.07$, respectively).

The association of digit replanted, Tamai level V (yes/no), history of tobacco use, repair of multiple veins, and small-vessel comorbidity with replantation success approached significance (set at $p < 0.15$). Therefore, these variables were included in a binary logistic model that assessed for their impact on replantation survival. Two factors found to predict replantation success were replantation of radial-sided digits ($p = 0.001$) and no smoking history ($p = 0.013$) (Table III). The final model correctly predicted the outcome of replantation in 71% of the cases.

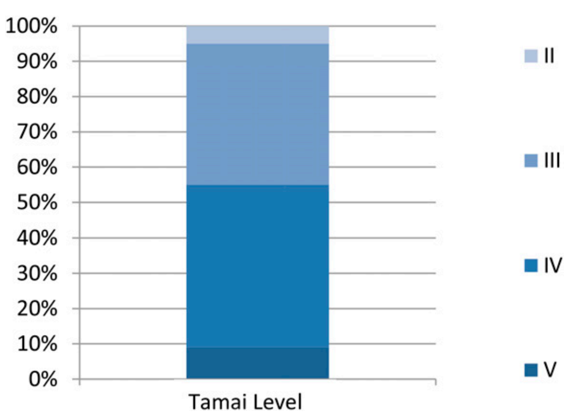

Fig. 3
Percentages of replantations by Tamai level.

Secondary Procedures

Fifty-nine percent of the digits that underwent replantation required at least one secondary procedure. One hundred and twenty-one secondary reconstructive procedures were performed in seventy-one digits. The most common secondary procedure was revision amputation (n = 56), followed by tenolysis (n = 15) and contracture release (n = 10). Seven cases required secondary soft-tissue-coverage procedures, including split-thickness or full-thickness skin grafting (n = 3), local flaps (n = 3), or a pedicled groin flap (n = 1).

Discussion

The aim of the present study was to report the current success of digit replantation in a large series treated in the U.S. We studied 121 digit replantations and found a 57% digit survival rate. This survival rate is substantially lower than the rates reported in the last fifteen years, which have ranged from 80% to 90%[5-8]. A review of the literature revealed that the vast majority of recent studies of large numbers of digit replantations were performed in centers outside of the U.S.[1,6,12,23]. The largest series from the U.S. (more than 300 digit replantations) showed a 76% survival rate but was published in 1988[14]. Other large series from the U.S. have shown a 56% rate of success of distal-tip replantation (in a study of fifty-three digits)[13] and a 91% rate of success of thumb replantation (in a study of 103 cases)[15], but we did not find any studies of series of greater than fifty digit replantations in the last ten years.

In order to report on our large series, we used the combined experience of multiple surgeons over a 12.5-year period at two academic level-I trauma centers that provide twenty-four-hour microsurgical coverage but are not dedicated microsurgical centers. Whereas this volume of digit replantations (an average of five replantations per institution per year) is low, recent U.S. trends in replantation surgery suggest that large teaching hospitals such as ours are managing the majority of amputation injuries[24,25]. Using the Nationwide Inpatient Sample, Barzin et al. demonstrated a significant decrease in the number of replantations performed during the years 1998 to 2007[26], a time period overlapping with that in our cohort. An epidemiological study of digit replantation in U.S. hospitals in 1996 demonstrated that digit replantation was performed in only 15% of the hospitals included in the investigation. Of those, 60% performed only one replantation in 1996 and only 2% (eighteen hospitals) performed more than ten that year[27]. In light of these trends, we believe that our modest volume and success rate offer an accurate depiction of the current practice of digit replantation in the U.S.

The modest success following digit replantation at our institutions may justify the concern that limited volume has a negative impact on replantation survival. Weiland et al. were among the first to show that replantation survival rates increased with surgeon experience[28]. Several authors have expressed concern that the declining number of digit replantations performed in the U.S. may result in diminished confidence and experience with microsurgery among hand surgeons[3,16,25]. To better manage the decreasing volume of replantation cases, some have suggested that specialized microsurgical teams should be created at regional specialty centers in the U.S., as has been done in other countries[14-18]. Currently, such dedicated microvascular staff and teams do not exist at either of our participating centers. In this investigation, we did not find that the surgeon's number of years in practice significantly affected replantation survival. However, specific data on the total number of replantations performed by each surgeon would likely have provided a more accurate gauge of surgeon experience. Another explanation for the seemingly low digit survival rate following digit replantation in the present study may be publication bias in the existing literature, with surgeons deciding not to report results when they fall unfavorably outside the accepted range.

We analyzed several other factors to determine their effect on the outcome of digit replantation. Positive predictors of replantation success included radial-digit replantation (thumb, index, or long finger) and no history of tobacco use (Table III). In an analysis of factors influencing survival following digit replantation, Dec found that the male sex, thumb replantation, a non-sharp mechanism of injury, and diabetes were associated with replantation failure[12]. In that study, tobacco use failed to reach significance. Li et al. found that a non-sharp injury mechanism, tobacco use, and use of vein grafts were significantly predictive of replantation failure in 211 patients[23]. Similarly, Waikakul et al. found that a non-sharp mechanism of injury and tobacco use negatively affected digit survival[8]. We did not find the mechanism of injury (sharp, crush, or avulsion) or ischemia time to influence digit survival significantly. However, our study was likely underpowered to detect these previously established differences, and selection bias may also be a factor. Beris et al. suggested that diseases affecting peripheral circulation including atherosclerosis, disease of connective tissue, autoimmune disease, and diabetes may reduce digit survival rates[24]. Heistein and Cook suggested diabetes as a predictor of failure, but the numbers in their cohort were insufficient to demonstrate significance (six of their fifty-three patients had diabetes)[13]. In our study, we categorized patients with diseases known to affect peripheral circulation into a small-vessel-comorbidity group. Small-vessel comorbidity approached, but did not reach, significance as a predictor of digit replantation failure. To our knowledge, a similar comorbidity category has not been used in a previously published study and was developed ad hoc for this investigation, but the specific comorbidities that we considered were based on consensus medical evidence indicating an effect on small peripheral vasculature.

There were several limitations of the present study, which are common to any retrospective review. Patients may have been lost to follow-up and then received a subsequent surgical procedure at another institution following the index procedure. However, given that our institutions are the primary replantation centers for our regions and because of the complexity of digit replantation, we believe that this is unlikely. Notably, a large number of surgeons performed the replantations in this series, and a small number of replantations were performed by each surgeon. Our experience is consistent with the recently reported observation that 62% of surgeons who perform replantations perform fewer than five per year[16]. The use of the combined experience of multiple surgeons at two institutions inherently introduced variability in the treatment provided (e.g., microsurgical expertise, operative techniques, anticoagulation, and decision-making for re-exploration). However, this limitation reflects the current practice of replantation surgery in the U.S., where dedicated replantation teams and microsurgical specialty centers are rare. We believe, therefore, that these limitations make our results generalizable to other level-I trauma centers in the U.S. Our specific aim was to determine the success of digit replantation at our institutions; however, we also assessed factors that may have affected digit survival.

Our digit replantation survival rate of 57% is substantially lower than predicted on the basis of data presented in the existing literature. These data help to more accurately inform patients and surgeons of realistic expectations and reinforce the need to carefully select patients for digit replantation. Our results reflect current practice and highlight the importance of a system-wide assessment of our replantation practices in the U.S. We believe that we must reassess indications for replantation, current microsurgical training, coding and reimbursement, and the concept of specialized microsurgical centers in order to optimize surgical outcomes. ■

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